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LITERATURE REVIEW OF ULTRAVIOLET RADIATION SYSTEMS AND ASSESSMENT OF THEIR USE IN AQUACULTURE

by

J.W. Bernstein

Contract by Saskatchewan Department
of Tourism and Small Business

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1. HISTORICAL

The first recorded discovery of bactericidal effects of radiant energy from sunlight was recorded by Downes and Blunt in 1878 (Jepson, 1973; Dupree, 1979). They observed the effect of sunlight on a mixture of microorganisms, concluding that radiation of short wavelength was responsible for their destruction. Ward (1893) confirmed that the ultraviolet portion of the solar spectrum was responsible for the bactericidal action of sunlight (Wheaton, 1977).

In 1901 Peter Cooper Hewitt invented a mercury vapour arc lamp which proved to be the prototype of those in use today. This lamp, allied with the discovery in 1906 that quartz, with its high melting point, low coefficient of expansion and transparency in the UV region was an ideal material for lamp envelopes, gave stimulus to research into the bactericidal properties of UV (Jepson, 1973).

The first recorded attempt to utilize UV for disinfection of water is attributed to Cernovedeau and Henri (1910). Between 1916 and 1928 UV sterilization was applied by at least four water authorities in the United States.

The initial favour placed in the technique waned considerably from the water supply aspect, largely due to the increasing use of chlorination in 1920's, allied with the difficulties experienced with reliability and maintenance of UV equipment and the relatively high costs associated with the process.

In 1929 Gates reported on the spectral regions actively responsible for germicidal action. Gates and subsequent workers demonstrated the similarity between these action spectra and the absorption spectra of nucleic acids.

Other studies investigated factors affecting the efficiency of UV treatement and since the late 1950's utilization has been expanding in fields such as brewing, dairying, pharmaceuticals, fish rearing and air conditioning, in addition to drinkable water (Jepson, 1973).

The killing effect of UV radiation on bacteria, viruses, and other small organisms is a function of the wavelength. Keller (1965) reported that the most effective wavelength is 2600 Anstrom Units (). The effectiveness decreases rapidly on either side of the peak and at 3200 and 7000 it drops to 0.4 and 0.002% respectively. Hoffman (1974) reported that 2537 is effective and practical for killing certain fish pathogens and is non-toxic to fish (Dupree, 1979).

2. CHARACTERISTICS OF UV EQUIPMENT

The use of low-pressure UV lamps and reflectors mounted over water surfaces is not widely used, this type of equipment being adversely affected by low ambient and water temperatures. Instead, units currently in production for water disinfection utilize low or medium-pressure mercury arc discharge lamps in quartz (Jepson, 1973).

These submerged UV treatment systems utilize a lamp submerged or surrounded by water. The lamp slides through a tube made of UV transmitting glass or quartz. This tube keeps water from contacting the UV lamp but allows the radiation to be absorbed by the water and the microorganisms in it. The tube keeps the water away from the lamp. Thus water temperature has only limited influence on lamp output (Wheaton, 1977).

As previously mentioned UV radiation lies between 150 and 4000. The band between 2000 and 3100 is called the abiotic region since it is here where the most lethal effects on microorganisms occur (Jepson, 1973). Once the dosage needed is determined, the physical size of the unit (i.e. the number of UV lamps) can be selected to provide the necessary flow rate through the unit (Wheaton, 1977).

Many types of lamps produce UV radiation, but nearly all that emit significant UV radiation contain mercury vapour. Electrical current passing through the vapour excites mercury atoms to various energy states. As the atoms revert back to lower energy states, they emit radiation of very definite wavelengths (Wheaton, 1977).

Very low mercury pressures are characteristic of low pressure mercury vapor lamps. The low pressure lamps are most widely used for several reasons. They are relatively inexpensive; the low pressure

mercury vapour lamps emit about 95%-85% of their radiation in a narrow band centered around 2537. This emission is very close to 2600, the wavelength producing the most effective germicidal action (Wheaton, 1977).

3. MECHANISM OF KILL

The destructive or killing effect of UV on bacteria, fungi, viruses and other small organisms is a function of wavelength (Wheaton, 1977). At a wavelength of 2537, UV light interacts particularly strongly with the purine and pyrimidine components of the deoxyribonucleic acid (DNA) of microorganisms (Flatow, 1980; Rosenthal, 1981). Water temperature has little effect on the bactericidal effects of radiation (Koller, 1965; Dupree, 1979).

4. MAINTENANCE

UV lamp energy and life. All low-pressure mercury vapor-type UV lamps - which represent most of UV generated for aquaculture - will lose approximately 10% of initial radiation output during the first 100 hours of operation (Flatow, 1981). After this, output levels off to a gradual decline during its remaining life (Cortelyou et al., 1951). For maximum generation of germicidal UV, lamps should be constructed with synthetic quartz envelopes, rather than the soft, leaded glass used by some manufacturers (Flatow, 1981).

Longevity of a UV lamp depends on electrode life and solarization Electrode life declines with the number of times it is switched on and off. Solarization is the slow darkening of the inside of the lamp glass with continued exposure to UV radiation. Some of the mercury that has been vaporized condenses on the glass, filtering out an increasingly greater percentage of the UV rays being generated. The effects of solarization can be measured on an intensity meter. When the output has declined by 25% the effective life of the lamp has been reached and it should be replaced (Spotte, 1979). Output is a function of filament temperature which itself will change with a change in voltage (Cortelyou et al., 1951). The formation of biological films on submerged units also reduces the intensity of UV radiation (Rosenthal, 1981).

Standard incandescent lamps, especially in sizes 500 W or above, produce some UV in the germicidal range, but the percentage of UV produced per watt input is too small to allow use of them for germicidal applications (Wheaton, 1977).

UV lamp temperature. Maintaining UV lamp temperature within the range of 37.8^{o}C and 49^{o}C is extremely important as beyond these limits

there is a sharp decrease in radiation efficiency. The optimum range is 40° to 40.6°C, and that temperature can be maintained - after an initial warm-up of 1 minute - by placing the UV lamp(s) within quartz sleeves of proper diameter where the air-space provides the necessary insulating barrier. UV purifiers of this design operate equally well in arctic and tropical climates, regardless of water temperature (Flatow, 1981; Cortelyou et al., 1951).

It is impossible to predict the absorption coefficient for a given water sample; it can be found only by experimental determination. Distilled water transmits UV radiation well having a wavelength of 2537 or longer (Wheaton, 1977).

Water depth in the treatment unit should be sufficient to absorb 90% or more of the incident energy. Lower water absorption results in high UV absorption by the treatment box walls. Since this energy is not available for bactericidal kill, the treatment efficiency drops rapidly if the water depth is too shallow. Water deeper in the water column receives a lower intensity because of absorption of water above. For complete treatment, all the water must receive the required intensity and exposure time. Baffles can be placed across the direction of flow to create turbulence and help ensure that all water is properly treated (Wheaton, 1977).

Since UV rays probably cannot penetrate water to a depth of more than 5 cm (Spotte, 1979) control of dissolved organic matter and detritus particles is of major importance (Rosenthal, 1981).

The flow rate through the system is determined by UV intensity, physical size of the treatment area, (Chamber), species of microorganism to be killed and turbidity (Wheaton, 1977).

Although dosage might appear to be adequate, the effective residence time in a particular device could be less than the calculated residence time, owing to non-uniformity of flow (Tobin et al., 1983).

Whether UV light dosage is being achieved can be evaluated by measuring the UV light intensity at the periphery (i.e. at the wall of the treatment chamber) and multiplying this figure by the residence time of the water being treated at the particular flowrate. Residence time is calculated from the volume of the chamber and the flow rate (Tobin et al., 1983).

A water flow restrictor should be used to ensure the rated flow capacity of the unit is not exceeded (Tobin et al., 1983).

The maximum allowable flow rate may be found experimentally by varying the flow rate through the system under highest turbidity conditions expected and monitoring the treatment unit outflow for the organism it is desired to kill. When the output just provides the desired microorganism count, that flow rate is the maximum the unit can treat under the worst conditions expected. This experimental procedure is time consuming and can be expensive, but is is the safest method if considerable risk would be incurred by insufficient treatment (Wheaton, 1977).

UV dosage. UV dosage refers to the total UV purifier unit, and should not be confused with individual UV lamp output. Dosage is dependent upon UV lamp output, flow rate, retention time and other factors. UV dosage is of extreme importance and should be calculated using a formula recognized and accepted by responsible agencies. Dosage is expressed in microwatt seconds per square centimetre (uWs/cm^2) (Flatow, 1981; Rosenthal, 1981).

The germicidal action of UV is wavelength dependent, with peak disinfection efficiency at 2600 falling practically to zero at 3200 (Jepson, 1973).

US Public Health Service recommends UV (2537A) to be applied at a minimum dosage of 16,000 uWs/cm for human drinking water (Tobin et al., 1983; Jepson, 1973; Hoffman, 1974). Herald et al., (1970) state that the requirements for good drinking water are not high enough for a good fish water.

Most commercial UV water treatment devices provide a UV dosage of about 30,000 uWs/cm^2 when operated at their design flowrates (Tobin et al., 1983). Note this says nothing about other influencing factors e.g. turbidity.

The lethal dosage varies with microorganism species, water turbidity, water depth and other factors (Wheaton, 1977). To ensure destruction of microorganisms, the dosage must be high enough to counteract the physical size and shape of the microorganisms. Reports of photoreactivation of certain microorganisms are due to less than total destruction because of insufficient dosage. The larger or more flagellated microorganisms require higher dosage, especially Gram-negative bacteria (Flatow, 1981).

If pathogens requiring higher dosage should enter the system at a later date, control is maintained by decreasing the flow rate to effictively increase dosage levels. This may require addition of parallel units to provide initial flow rate (Flatow, 1981).

The treatment dosage (intensity times exposure time) may be determined from information for the particular species in question, then

adjusted for turbidity (by increasing the dosage or removing the turbidity with filters) (Wheaton, 1977).

5. FACTORS AFFECTING EFFICIENCY

Turbidity has a considerable influence on the effectiveness of UV treatment. This has been demonstrated by Sanders et al., (1972) for salmonid hatchery water. Although turbidity is a UV transmission inhibiting factor, it is more important to know what is causing the turbidity (Flatow, 1981).

Impurities in the water reduce transmission significantly. Multivalent salts and organic matter reduce transmission. Iron salts and organic matter generally reduce transmission more than similar quantities of alkali salts (Phillips & Hanel, 1960).

UV absorbing particulates will exert a screening effect and may thus exclude some organisms from the germicidal irradiation (Cortelyou et. al., 1951).

Because of their occurrence in soils, streams and other water bodies such as lakes and fish ponds, clay minerals are closely associated with microorganisms in their natural habitat (Bitton et al., 1972).

Bitton, Henis & Lahav, (1972) looked at effects of various clay minerals and humic acid on bacterial survival exposed to UV irradiation. A protective effect was observed and found to depend on the specific light absorption and light scattering properties of the clay mineral and the humic acid used. They found that the higher the specific absorption, the better the survival after UV irradiation.

In the UV range, the light absorbance is the sum of both scattering and specific absorption, and the proportion of these two components depends on factors such as clay mineral type, concentration and particle size (Bitton et al., 1972).

Bitton et al., (1972) found that clay mineral had a significant protective effect on bacteria. Bacterial survival was directly correted with the specific absorption of the clay minerals and the humic acid under study, rather than the bacterial absorbance.

Color of water. The nature of the color-causing agent(s) determines whether or not UV transmission is inhibited (Flatow, 1981).

Iron. Iron content inhibition of UV transmission can be offset by increased dosage (Flatow, 1981).

Because particulate matter interferes with UV irradiation, water must be pretreated before UV treatment. Therefore, this review will include some information on filtration (Hoffman, 1974).

Many authors state that filtration of water prior to irradiation is very important (Hoggman, 1974; Spotte, 1979; Spotte & Buck, 1981; Gratzek et al., 1983).

Occasionally filters for removal of solids and dissolved organics are used in conjunction with fresh water dilution to reduce turbidity and ensure adequate UV transmission. Suspended solids and organics should be removed prior to carbon adsorption or charcoal replacement becomes too expensive (Geiger et al., 1982).

UV transmission rates increase as organic levels decrease. Higher transmission levels resulted in a greater reduction by the UV unit in comparative trials (Geiger et al., 1982). Biological treatment followed by sand filtration of an effluent having moderate organic concentrations resulted in a clear high quality effluent that did not require carbon adsorption prior to UV treatment (Geiger et al., 1982).

The filters are an essential part of treatment because the upper limit of UV effectiveness borders on 30 microns, and removal of the

particles above 15 microns by filtration helps further to ensure complete sterilization of the smaller organisms by UV (Hoffman, 1975).

Filtration by rapid sand or other types of filters clarifying to at least 25 microns or smaller should be used both for UV effectiveness and feeding efficiency. An activated charcoal filter may also be required to control color or excess organic matter (Flatow, 1981; Hoffman, 1975).

Water may also contain suspended or dissolved material, transparent to the eye but refractory to UV irradiation. This may be as important as visible suspended solids (Hoffman, 1974).

It has been found that regardless of the depth of the sand in a sand filter, only the top 1 1/2 inches of sand has any filtering efficiency. Truly effective filtration was achieved only after the filter became dirty. A newly washed filter may require 24 hours to return to its normal efficiency (note: some bacterial solutions may now be added to increase this process). The most effective sand and gravel filter is one which is extremely dirty and bacteriologically impossible (Herald et al., 1970).

A higher bacterial content is often observed after filtration, what ever the pore size. Often filters are not fine enough to retain bacteria. However, they are capable of retaining most of the particles of which bacteria may have been attached. It is also possible that bacterial populations become established in the filtration system, escaping periodically and thus raising the concentration of the bacteria in the filter culture medium (Prieur & Carval, 1979; Flatow, 1981; Giles & Danell, 1983).

Lastly another factor causing contamination and decreased efficiency is introduction of airborne organisms, particularly of the Pseudomonas group (Flatow, 1981). Tanks can be covered to prevent penetration of dust and other foreign objects into the water (e.g. storage tanks) (1,6,20) (Flatow, 1981; Spanier, 1978; Brown and Russo, 1979).

6. FAIL-SAFE DEVICES

Various studies have indicated that only by careful testing and monitoring procedures can a purchaser or control agency be assured that the UV devices will perform in an effective manner (Tobin et al., 1983; Geiger et al., 1982; Hoffman, 1974). Additionally Tobin et al., (1983) tested three commercial UV sensor devices; one was satisfactory, the second unit was set too low by a factor of 1.6, and the third unit was set too low by a factor greater than 2.

All UV water treatment units should be provided with an accurately calibrated light sensor that responds to 2537 wavelength UV light and is coupled to a fail-safe device that prevents water flow or activates an audible alarm when the water receives a dosage below the minimum (Tobin et al., 1983; Geiger et al., 1982).

A tube cleaner (manual)is an indispensable part of the system. Any surface, such as the glass tube, that is in contact with water will eventually collect particles and/or fouling on itself and this will block the UV radiation. Labor requirements for maintenance become high as system size increases. An automatic cleaning system can be installed (Wheaton, 1977; Hoffman, 1974).

UV bulbs also lose intensity with use, so it is additionally to have reliable UV sensory equipment available, or permanently installed to test them (Hoffman, 1974).

Control of the Process

The only way of determining the efficiency of the process is by bacteriological tests. Control may be exercised by the following:

1. In the event of power or tube failure prevent a flow of water through the unit automatically.

2. Sense UV intensity at the wall of the radiation chamber and record the level.
3. Use a pre-set sensor suitably placed, which can detect a loss in UV output and to control warning indicators, which will shut down or switch to standby equipment.

7. BACTERIAL TESTING

To determine whether adequate dosage is being provided, bacterial challenge experiments can be undertaken (Tobin et al., 1983). Often analyses are performed according to procedures described in Standard Methods (1975) (Geiger et al., 1982). Total bacterial numbers can be counted using a standard plate count method (Giles and Danell, 1983). Various types of media are used depending on the bacterial species being investigated (Wedemeyer and Nelson, 1977; Herald et al., 1970; Gratzek et al., 1983). Alternatively some authors used streaking or coating the surface of agar plates to determine growth. The latter is not truly quantative as the water sample size may be too small.

In one experiment on bacterial load in water, a comparison was made between a general bacterial count (including Gram-negative and Gram-positive types) and a specialized count of just Aeromonas hydrophila, a common Gram-negative bacteria found in surface waters (Gratzek et al., 1983). This latter bacteria also often causes problems in hatcheries when fish are under stress. They found that both counts were reliable in estimating aquatic bacterial load. This technique would be useful in fish hatcheries.

As previously mentioned (i.e. clay minerals and humic acid) various factors can interfere with bacterial killing. It is recognized that clumping of bacteria can yield the same effect as screening due to density of population or UV absorbing particles. At low intensity ranges the germicidal energy cannot effectively reach the "center" of such an aggregate (Cortelyou et al., 1951).

Bacteria can enter a system through atmospheric contamination (Prieur and Carval, 1979).

Bacteria are often isolated from storage tanks and Pseudomonas is often the dominant genus present. This occurs even when the water has previously been irradiated (Murchelano, Brown and Bishop, 1975). Bacterial counts are often significantly lower in water from a sampling valve immediately after irradiation whereas the numbers in either the storage tanks or aquaria are significantly higher (Gratzek et. al., 1983).

8. HATCHERIES AND UV SYSTEMS

The utilization of high dosage germicidal ultraviolet water purification systems has become an indispensable tool in controlling fish diseases in hatcheries (recycling and raceway systems), and particularly in heated effluent aquaculture (Flatow, 1981) (Spotte, 1979).

Investigators have long been interested in the use of UV irradiation for the prevention of diseases associated with aquaculture (Brown and Russo, 1979). Burrows and Combs (1968) recommended the use of UV irradiation to prevent disease in a fish hatchery using reused water. High rate sand filtration followed by UV irradiation was effective in removing fish pathogens from Columbia River water.

Flatow (1981) states that control of pathogens in fish hatcheries has proven to produce larger, stronger and healthier animals.

UV has also been shown to be effective in salt water systems (Flatow, 1981). Filtration followed by UV irradiation of salt water in a closed aquarium system (Herald et al., 1962), caused 98% bacterial reduction. An UV unit for continuous flow salt water system (Culverhouse, 1971) killed more than 90% of bacteria (Hoffman, 1974). UV irradiation is slightly less effective in salt water than fresh water because of differences in concentrations of inorganic solutes (Rosenthal, 1981). Salt water absorbs more UV than most freshwater because of its higher ion content (Wheaton, 1977). Thus there are probably differences due to soft and hard water also that need to be taken into consideration.

Work with Invertebrate Hatcheries has also shown UV irradiation to be useful. Brown and Russo (1979) seeded filtered sea water with 1 of 5 oyster pathogenic bacteria. UV irradiation was at a dose of 93,312 to

155,520 uWs/cm^2. The data suggest that when a pathogenic bacterium is present the potential for disease is much greater in non-UV treated sea water.

8.1 UV Effects of Pathogenic Agents

Effective exposure level.

Hoffman (1974) assembled most of the published data on effects of UV light on fish pathogens in order to determine the effective exposure (dosage) level. Table 1 gives data on the energy requirements for 90 to 100% kill of various organisms.

From these data, it is clear that the effectiveness of UV light is dependent on the size of the organism. As little as 3620 uWs/cm^2 (=MWS) killed Aeromonas salmonicida (fununculosis) which is 0.5 - 1.0 microns wide (Normandeau, 1968), but 1,717,200 uWs/cm^2 were needed to kill Ichthyophthirius multifiliis trophozoites (Vlasenko, 1969) which are approximately 800 microns is diameter (Hoffman, 1974). The latter are large protozoan fish parasites. Experimental results reported in the literature have demonstrated that UV irradiation at 35,000 MWS will successfully disinfect waters containing Aeromonas salmonicida (furunculosis disease), Myxosome cerebralis (whirling disease), Saprolegnia sp (fungi), a small Trichodina sp (protozoan parasite) and other organisms of similar size (Hoffman, 1974). To prevent transmission of furunculosis Maisse et al., (1980) found an effective dose for salmonids to be 10,000 uWs/cm^2 and 330,000 uWs/cm^2 for Viral Hemorrhagic Septicemia (Rosenthal, 1981).

As different fish pathogenic agents require different UV dosages for effective killing, the minimum effective dosage of UV for hatchery

use has not been determined (Hoffman, 1974). The amount of UV required to destroy Staphylococcus albus is 5700 uWs/cm^2; for Paramecium (protozoan) 200,000; and for the mold spores of Aspergillus niger, 300,000 (Herald et al., 1970).

Minimum effective dosages of UV for some fish pathogens is listed in Table 1. Effective dosage for most fish pathogens has yet to be determined (Hoffman, 1974).

8.2 UV Effects of Viruses

Kabler et al reported that much longer contact times are required to inactivate viruses, compared with bacteria (Jepson, 1973). However others state the opposite (Flaton, 1981).

Infectious Pancreatic Necrosis virus (IPNV) and Viral Hemorrhagic Septicemia virus (VHSV) were diluted in clear tap water and then inactivated by passage through a laboratory constructed UV system at various flowrates. IPNV proved much more resistant. Maisse et al., (1981) concluded that for trout farming, UV protection of hatcheries against salmonid viruses would be practical only against VHSV and not IPNV.

Various strains of Cold Water Virus of Salmonids are effectively controlled by UV. As this virus is a problem in cold water situations, effective control is accomplished by using water temperatures at or above 14.5^{o}C while using UV to ensure destruction of the other disease agents stimulated by the higher temperature (Flatow, 1981).

8.3 UV Effects on Bacteria

UV destroys disease organisms which are smaller than 15 microns, including protozoans, bacteria and viruses (Hoffman, 1975).

Gram-negative bacteria.

Many Gram-negative bacteria, especially that rod types such as various strains of Pseudomonas, require higher germicidal dosage than is available from many UV units at rated maximum flow (Flatow, 1981). Normandeau (1968) reported that as little as 3620 uWs/cm killed A. salmonicida. Vibrio sp. and iron bacteria can be controlled by proper UV application (Flatow, 1981).

The differing sensitivity of organisms to UV can be influenced by the different stages in the bacterial growth cycle (Jepson, 1973).

Gram-positive bacteria can also be controlled by UV (Flatow, 1981).

Regrowth of bacteria in drinking water was shown to be due primarily to Pseudomonas sp. (gram-negative). It was observed that the increase in number of bacteria was accompanied by a decrease of individual species. Thus quantity and quality of bacteria may be changed after UV treatment.

8.4 UV Effects on Parasites

Although some fish pathogens larger than 15 microns in diameter may be removed from water supplies by various methods of filtration, alternative methods of water treatment are necessary for the removal or destruction of pathogens smaller than 15 microns in diameter (Hoffman, 1974).

UV irradiation of water at 2537 Angstrom units () wavelength has proven effective and practical for the destruction of certain protozoans and other pathogens and is nontoxic to fish. Wavelengths below 2000 produce ozone which is toxic to fish, and wavelengths above 3000 have proven less effective (Giese, 1967) (Hoffman, 1974).

Myxosoma Cerebralis (whirling disease)

When rainbow trout fry were exposed to water previously contaminated with M. cerebralis, filtered through 25 micron pore cartridge type filters and then irradiated with 2537 of UV light, infection of fry was prevented. Dosages were at 35,000, 43,000, and 112,000 uWs/cm^2 (Hoffman, 1974). This study found that the intensity of whirling disease is directly related to the intensity of infection (Hoffman, 1974). Greater dosage is required for larger organisms (Hoffman, 1974). It may be reasoned that a UV dosage sufficient to control this pathogen should also be sufficient to control the spread of bacteria and viruses between units of the system (Hoffman, 1974; Gratzek et al., 1983). In another study, (Hoffman, 1975) irradiation at 18,000 uWs/cm^2 reduced infectivity of M. cerebralis by 31-86% and 27,650 mWs/cm^2 reduced infectivity by 86-100%; even in the presence of a small amount of silt.

Ceratomyxa shasta.

This is an extremely virulent Myxosporidian parasite and can be effectively controlled by UV (Flatow, 1981). Schafer and Sanders et al., have suggested that the spread of C. shasta from infected to uninfected animals is not by direct fish to fish transfer. In a hatchery situation this would mean that C. shasta infection occurs only as a consequence of introducing the infective stage through the water supply and that disease transmission within the hatchery population is limited if, in fact, it occurs at all. Accordingly, water treatment systems should be of particular value in controlling this parasite or other organisms with a similar life cycle. No reduction in incidence of the disease was noted among fish exposed to high rate sand filtered water (Sander et al., 1972).

Filtration followed by UV irradiation of hatchery fresh water by the Oregon Fish Commission (1967) used 215,500 uWs/cm^2 while the Bonneville Hatchery used 360,000 uWs/cm^2; both effectively controlled C. shasta (Hoffman, 1974).

Bedell (1971) also indicated that C. shasta infections in rainbow trout could be prevented or greatly reduced by UV irradiation of the hatchery water supply (Sander et al., 1972).

Ichthyophthirius multifiliis

Gratzek et al., (1983), evaluated a closed fish culture recirculation system for UV effectiveness in preventing the spread of I. multifiliis. This is an extremely large protozoan fish parasite and the disease it causes is called "Ich". Water from various parts of the system in this study was analyzed bacteriologically to assess its effectiveness (Gratzek, et al., 1983). Analysis of the mortality patterns of the fish exposed to I. multifiliis demonstrated that the incorporation of UV light in an aquarium system significantly reduced deaths (Gratzek et al., 1983). While either one (91,900) or two (183,800 uWs/cm^2) UV lamps were operating, no I. multifiliis were observed microscopically on fish. All aquaria contained I. multifiliis infected fish when the UV light was turned off. When the UV light source was on, use of one or two lamps did not significantly affect the number of bacteria recovered (Gratzek, et. al., 1983).

The spread of I. multifiliis from one aquarium to another was controlled with 91,900 uWs/cm^2 of UV light. Minimum lethal dose of UV to kill tomites of I. multifiliis has been reported as 100,000 - 336,000 uWs/cm^2 from in vitro work (Hoffman, 1974).

Vlasenko (1969) reported that the 800 micron diameter I. multifiliis trophozoites required 1.7 x 10^6 uWs/cm^2 of UV irradiation for kill.

8.5 UV Effects on Fungal Pathogens

Fungal diseases have also been prevented with the use of UV (Loosanoff and Davis, 1963; Fisher et al., 1976; Brown and Russo, 1979). Various strains of Saprolegnia can be controlled. However, these fungi are quite large, and a much higher UV dosage is needed (Flatow, 1981). Fungus infections were found to be prevented in fish eggs and fry by UV irradiation of water passed through a sand-gravel or slag filter (Hoffman, 1974).

8.6 UV Systems and Stress

Fish subjected to environmental stress usually are more susceptible to infections resulting from invasions by common aquatic bacteria (Rosenthal, 1981). Fish have lowered resistance to pathogens when stressed. UV will not cure stress but the effects of stress and the dangers associated with it will be reduced if the fish is kept in a reduced pathogen environment (Flatow, 1981).

9. LIMITATIONS OF UV WATER TREATMENT

UV irradiation is generally more expensive than chemical treatment. The water to be treated must have good transmission characteristics for UV irradiation; pretreatment may be required (Jepson, 1973). There is no long term residual germicidal effect. Although UV irradiation may substantially reduce the bacterial concentration (Murchelano and Brown, 1975), such a medium recontaminates rapidly, reaching concentrations sometimes greater than those observed before treatment (Mevel, 1976; Prieur and Carval, 1979). Stored or piped water often becomes contaminated by photoreactivation, aerial contamination or other types of contamination (Tobin et al., 1983). Although UV can adequately sterilize water going into a fish tank, it cannot affect the water in the tank (Herald et al., 1970).

Herald et al., (1979) noted that the effectiveness of UV irradiation is limited to in vitro situations; e.g. the destruction of pathogens that are free-floating in the water. Organisms that are systemic, or attached to the exterior surfaces of their hosts, are unaffected and can only be controlled chemotherapeutically. Organisms shed into the water, or which detach from their hosts, thus represent a reservoir of contamination that cannot be eliminated from closed systems, if sterilization occurs at a single contact site (Spotte and Adams, 1981).

Spotte (1979) reported that some pathogens always survive, despite kill rates that sometimes approach 100% at the contact site. The degree of reinfection depending on the virulence and concentration of the pathogen and the immune status of the host. Although UV irradiation has been shown to effectively kill 99.99% bacteria (counts) of salmonid hatchery water, it should also be cautioned that the number of bacteria

necessary to transmit disease is difficult to predict (Bullock and Stuckey, 1977). Spotte and Buck (1981) studying the efficacy of UV sterilization observed that cutaneous and systemic infections in captive dolphins and whales, caused by the yeast Candida albicans, continued to flourish even though cell counts never exceeded 100 x 1^{-1} anywhere in the water system.

Disease causing organisms can thus be transmitted among cultured animals directly, short-circuiting the sterilizer completely. The result may be a high percent kill at the contact site that is not accompanied by a concomittant decrease in the incidence of disease or mortality. Herald et al., (1970) reported that mortality rates among exhibit fishes at a public aquarium were unchanged by installation of a UV sterilizer that lowered the total bacteria at the contact site by 98%. Spanier (1978) noted that mortality rates of bream (Sparus aurata) larvae were unaffected by UV sterilization of the recycled water, despite a substantial decrease in bacterial counts at the sterilizer effluent (Spotte and Adams, 1981).

Fish reared in UV treated water are not sterile, nor is the water, but the latter is cleaner. These fish are still capable of developing disease resistance and will be able to survive when planted. Some authors (Hoffman, 1975) feel that fish cultured under these conditions will survive as well as wild fish. They cite the example of salmon fingerlings moving from cold to warm water temperatures during their downstream migration. These fish have not developed resistance to warm water diseases and yet still survive. Larger hatchery reared fish with higher energy reserves might survive at a higher rate (Hoffman, 1975).

10. ADVANTAGES OF UV WATER TREATMENT

The water does not change in chemical composition and does not produce toxic residues (Jepsen, 1973). The equipment for its production is readily available and easily installed. As UV has no residual, overdosing is impossible, and thus sufficient dosage can be maintained (Flatow, 1981).

Treatment rates can be varied.

The destructive rate is rapid.

Chemical handling is eliminated, e.g. chlorination.

Automation is possible.

Giles and Danell (1983) used UV to dechlorinate city water (25,000 uWs/cm^2).

Studies have shown that when a pathogenic bacterium is present the potential for disease is much greater than in non-UV treated water (Brown and Russo, 1979). Spanier (1978) found that the mortality rate of experimentally wounded fish kept in sea water treated with UV radiation was significantly lower than that of controls. Some authors have felt that UV irradiation can be as effective as nitrofurazone in preventing infection in injured fish (Spanier, 1978).

Fish receiving treated water grew larger than comparable fish in untreated water contaminated with spores of M. cerebralis (whirling disease)(Hoffman, 1974). Both individual animal production (growth) and density can be increased with UV treated water compared to untreated (Flatow, 1981).

UV Treatment Design Summary (Wheaton 1977 with modification).

1. Determine dosage of UV radiation necessary to kill the target organisms (see Table 1).

2. Adjust dosage for water turbidity.
3. Determine flow rate needed (manufacturer states this).
4. Determine number and type of UV lamp(s) to be used to provide required dosage to treat required flow rate.

11. RECIRCULATION AMD RACEWAY (SINGLE PASS) SYSTEMS

Some authors feel that UV systems are best for laboratory and small aquacultural operations (Wheaton, 1977; Burrows and Combs, 1968). The relatively small amount of supplemental water required in recycle hatcheries makes water sterilization practical (Burrows and Combs, 1968) Gratzek et al. (1983) conclude that UV irradiation is good for multi-aquarium closed systems. Others state that UV is best for small systems since turbidity can severely limit the flow rate (Rosenthal, 1981). Studies have shown that UV irradiation of recycle hatchery water can be an effective disinfectant, can restrict the movement of pathogens and in some cases eliminate the pathogen (Hoffman, 1971; Brown and Russo, 1979). However it should be noted that when the water is recycled any apparent efficacy of a UV sterilizer, based on kill rate, is something of an artifact, because the mass of pathogens in the immediate vicinity of the cultured animals is always greater than the mass in the sterilizer effluent. Equilibrium is never attained and the entire system will not be rendered disease free, even when the sterilization process is 100% effective (Spotte and Adams).

Additionally, UV irradiation of raw influent and hatchery discharge water has been shown to be effective in lowering the numbers of pathogens into receiving waters (Hoffman, 1975; Brown and Russo, 1979). In a test installation, 125 gallons per minute of Columbia River water was sterilized by passing it through two 30-inch diameter high speed sand filters rated at 15 gallons per minute per square foot and then through an 18 lamp UV irradiation unit divided into three series of six 40 watt lamps each with a capacity of 42 gallons per minute series. (It should be noted that high rate sand filters need frequent backflushing).

This system may have been developed as an alteration of an already existing facility rather than a new design facility. In the raw water some trout were killed by Columnaris disease and the rest died from C. shasta. Fish in the treated water remained healthy (Hoffman, 1975; Burrows and Combs, 1968). Similar results were reported by Sanders et al (1972) and Bedell (1971). As long as the system is functioning properly UV water treatment of hatchery discharge water has been shown to be effective in reducing bacterial numbers in hatchery raceway systems.

12. CONCLUSIONS

UV treatment is an effective tool for disinfecting water in aquacultural systems (recirculating or raceway) when the system is functioning correctly. In both fresh water and seawater, sterilization will be incomplete in the presence of organics and suspended solids. Pre-treatment of water is required.

In a closed (recirculation) system pathogens should be removed from recirculated water. UV light at or near 2537 has long been used as a bactericide and has been recognized as useful for destroying certain fish pathogens (Hoffman, 1974, 1975; Bullock and Stuckey, 1977; Herald, Dempster, Wolters and Hunt, 1962). Spotte and Adams (1981) in a mathematical model, demonstrated that UV radiation may substantially decrease the number of pathogens at the sterilizer effluent, but the number of pathogens in the immediate vicinity of cultured animals is always greater than the number at the sterilizer effluent. Some fish culturists erroneously believe that treatment of recycled water with UV irradiation will reduce the number of bacteria in an aquarium (Gratzek et al, 1983).

Results of bacterial studies support the findings of Spotte and Adams (1981). Gratzek et al (1983) found no significant differences in bacterial counts from reservoir or aquaria water when the UV light was either on or off, but a significant difference existed between the sterilizer effluent (lower) and the reservoir and aquaria (Gratzek et al, 1983). Thus UV treatment will not control an organism which reproduces within the units of the system. But the use of UV was found to be highly effective in preventing cross-contamination among aquaria of a closed

fish culture recirculation system (Rosenthal, 1981; Gratzek et al, 1983).

Most reported work testing UV systems has been carried out on recirulation systems. However UV water treatment has been shown to be most effective at the point source of treatment - thus treatment of hatchery discharge water from raceway systems can be effective as long as the UV system is functioning properly. The major consideration with raceway systems is the quantity of water passing through and corresponding costs of appropriate UV systems.

When UV systems are functioning properly there is no question that pathogens are removed, however since there are no residual effects nothing can be said concerning the water system after it has passed this site.

Because proper functioning is so essential it is necessary to have failsafe devices in conjunction with UV systems. Inflowing water is constantly changing while many constituents in the water can affect UV penetration and flow rate may change. In addition lamps age, become dirty or otherwise are affected and their output will change. Thus a meter or sensory device which will respond by shutting down the system, shifting to another system and/or setting off an alarm is necessary to maintain disinfection. Commercially available equipment can be obtained that will deliver UV intensities ranging from 16,000 to 112,000 uWs/cm^2, varied by flow regulation and monitored by built-in sensors (Hoffman, 1974). However it is necessary to check these systems. The UV must always be the last stage of treatment in any system. Even if spring water is used, UV can be used to eliminate water or airborne pathogens (Flatow, 1981).

12. RECOMMENDATIONS

1. A market survey should be undertaken to evaluate what is available in UV Treatment Systems. This would include specifications provided by the manufacturer (at the minimum information on dosage and flow rate requirements); whether meter and/or failsafe devices accompany the system; if not, whether they can be acquired and attached; and costs of the entire system and its components.
2. Filters are essential as the upper limit of UV effectiveness borders on 30 microns. Removal of particles above 15 microns helps further to ensure sterilization of smaller organisms. Twenty five microns has been suggested as the upper limit for UV effectiveness. Most filters reported have been some type of sand filter.
3. Failsafe Devices. All UV treatment units should be provided with an accurately calibrated light sensor that responds to 2537 wavelength UV light. A control flow device should be installed to make sure that the recommended or calculated flow rate is not exceeded. With these a failsafe device that prevents water flow or activates an alarm when the water receives a dosage below the minimum can be installed. These type of devices are available - such as from Spectronics Corporation products. A cleaning method for the tube should also be part of the system.
4. Bacterial contamination of storage water. Although covering storage water tanks decreases contamination, the best and most reliable treatment is treatment of inflowing water to fish tanks in recirculating hatcheries and treatment of water just before discharge in raceway systems.

5. Efficiency testing of the UV System should be carried out when it is first set up using standard bacterial plate count procedures. (See Appendix for procedure). This will ensure that the set dosage of the treatment is effective. From that point on if monitored, can be maintained through meters or meters and failsafe devices. Bacterial plate counts can be done using Aeromonas hydrophila on Rimler and Shotts modified media to estimate total bacterial load. It is less expensive and more efficient to monitor a UV System with builtin measuring devices than to continuously test the efficiency bacteriologically.
6. Table 1 lists available information on tests of UV systems reported in the literature. Minimum lethal dosage has not been determined in most cases and many organisms still need to be tested to determine effective treatment dose. Dosages stated in Table 1 are specific for the organisms listed. All reports include some sort of prior filtration before treatment.

REFERENCES

Bedell, G.W. 1971. Eradicating Ceratomyxa shasta from infected water by chlorination and ultraviolet irradiation. Prog. Fish Cult. 33: 51-54

Bitton, G. Y. Henis, N. Lavav, 1972. Effect of several clay minerals and humic acid on the survival of Klebsiella aeroglenes exposed to ultraviolet irradiation. App. Microbiol. 23:5-870.

Brown, C. and D.J. Russo, 1979. Ultraviolet light disinfection of shellfish hatchery sea water. I. Elimination of five pathogenic bacteria. Aquaculture 17:17-23.

Bullock, G.L. and H.M. Stuckey, 1977. Ultraviolet treatment of water for the destruction of five gram-negative bacteria pathogenic to fishes. J. Fish. Res. Board Can. 34:1244-1249.

Burrows, R.E. and B.D. Combs, 1968. Controlled environments for salmon propogation. Prog. Fish Cult. 30:123-136.

Cortelyou, J.R. et al 1954. The effects of ultraviolet irradiation on large populations of certain water-borne bacteria in motion II. Some physical factors affecting the effectiveness of germicidal ultraviolet radiation. Appl. Microbiol. 2:269.

Dott, W. 1983. Qualitative and quantitative examination of bacteria found in aquatic habitats. 6. Communication: bacterial regrowth in drinking water.

Dupree, H.K. 1979. An overview of the various techniques to control infectious diseases in water supplies and in water reuse of aquaculture systems. Proc. Bio-engineering Symposium for Fish Culture.

Fisher, W.S., E.H. Nilson, L.F. Follett, R.A. Shlesser, 1976. Hatching and rearing lobster larvae (Homarus lamericanus) in a disease situation. Aquaculture 7:75-80.

Flatow, R.E. 1981. High dosage ultraviolet water purification: an indespensible tool for recycling fish hatcheries and heated effluent aquaculture. Proc. World Symp. on Aquaculture in Heated Effluents and Recir. Sys. Stavanger 28-30 May, Vol. 1 Berlin.

Geiger, E.L., F.W. Wheaton, R.B. Brinsfield, J.E. Alleman 1982. Crab processing plant wastewater treatment using biological, physical and ultraviolet processes. Amer. Soc. of Agric. Engin. (Maryland).

Giles, M.A. and R. Danell, 1983. Water dechlorination by activated carbon, ultraviolet radiation and sodium sulphite. Water Res. 17-6):667-676.

Gratzek, J.B., J.P. Gilbert, A.L. Lohr, E.B. Shotts Jr., J. Brown, 1983. Ultraviolet light control of Ichthyophthirius multifiliis Fouquet in a closed fish culture recirculation system. J. Fish Dis. 6:145-153.

Herald, E.S., R.P. Dempster and M. Hunt, 1970. Ultraviolet sterilization of aquarium water. Drum and Croaker (Spec. ed.) U.S. Dept. Interior. W. Hagen (ed).

Hoffman, G.L. 1974. Disinfection of contaminated water by ultraviolet irradiation, with emphasis on whirling disease (Myxosoma cerebralis) and its effect on fish. Tran. Am. Fish Soc. 103:541-550.

_____ 1975. Whirling disease (Myxosoma cerebralis): control with ultraviolet irradiation and effect on fish. J. Wildl. Dis. 11:505-507.

Jepson, J.D. 1973. Disinfection of water supplies by ultraviolet radiation. Wtr. Treat. Exam. 22:31-175.

Koller, L.R. 1965. Ultraviolet radiation. 2nd Edition Wiley, New York, 312 pp.

Loosanoff, L. and H.L. Davis 1963. Rearing of bivalve mollusks In: F.S. Russel (ed). Advances in Marine Biology V.1. Acad. Press, London, 136 pp.

Maisse, G., M. Dorson, C. Torchy 1981. Inactivation de deux virus pathogenes pour les salmonides (virus de la necrose pancreatique infectieuse et de la septicemie hemorragique virale) parles rayons ultraviolets. Proc. World Symp. Aquac. Heated Effluents and Recir. Sys. Stavanger 28-30 May, V.1 Berlin.

Mevel, G. 1976. Controle bacteriologique quantitatif de l'eau de mer utilisee pour les elevagesde larves de bivalves. Rapp. D.E.A. Oceanographie biologique, Brest, 71 pp.

Murchelano, R.A. and C. Brown and J. Bishop 1975. Quantitative and qualitative studies of bacteria isolated from sea water used in the laboratory culture of the american oyster Crassosltrea virginica. J. Fish Res. Board Can. 32:739-745.

Prieur, D. and J.P. Carval 1979. Bacteriological and physico-chemical analysis in a bivalve hatchery: techniques and preliminary results. Aquaculture 17:359-374.

Rosenthal, H. 1981. Recycling systems in Western Europe. Proc. World Symp. on Aquaculture in Heated Effluents and Recirculation Systems. May 28-30, Stavanger, Berlin.

Sander, J.E., J.L. Fryer, D.A. Leith and K.D. Moore 1972. Control of the infectious protozoan Ceratomyxa shasta by treating hatchery water supplies. Prog. Fish. Cult. 34:13-17.

Spanier, E. 1978. Preliminary trials with an Ultraviolet liquid sterilizer. Aquaculture 14:75-84.

Spotte, S. 1979. Fish and Invertebrate Culture: water management in closed systems (2nd edition) Wiley, New York, 179 pp.

Spotte, S. and G. Adams 1981. Pathogen reduction in closed aquaculture systems by ultraviolet radiation: fact or artifact. Mar. Ecol. Prog. Ser. 6:295-298.

Spotte, S. and J.D. Buck 1981. The efficacy of ultraviolet irradiation in the microbiological disinfection of marine mammal water. J. Wildl. Dis. 17:11-16.

Tobin, R.S., D.K. Smith, A. Horton, V.C. Armstrong 1983. Methods for testing the efficacy of ultraviolet light disinfection devices for drinking water. Research and Technology. AWWA.

Vlasenko, M.I. 1969. Ultraviolet rays as a method for the control of diseases of fish eggs and young fishes. Problems of Ichthyol. 9:697-705.

Wheaton, F.W. 1977. Aquacultural engineering. Wiley, New York, 708 pp.

Compendium of Methods for the Microbiological Examination of Food

Prepared by the APHA Intersociety/Agency Committee on

Microbiological Methods for Foods

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